THE ECOLOGY OF THE CENTRAL COASTAL AREA OF NEW SOUTH WALES. IV.

FOREST TYPES ON SOILS FROM HAWKESBURY SANDSTONE AND WIANAMATTA SHALE.

By Ilma M. Pidgeon, M.Sc., Linnean Macleay Fellow of the Society in Botany.
(*From the Botany School, University of Sydney.*)

(Five Text-figures.)

[Read 25th June, 1941.]

Introduction.

It is becoming apparent that the existing systems of ecological nomenclature cannot be satisfactorily applied to the classification of Australian forests. Formations and associations, as defined by Clements, can be recognized (Pidgeon, 1937), but beyond this stage the classification is unsuitable. This is exemplified by attempts to describe the sandstone forests of the central coastlands of New South Wales. Accordingly, the purpose of this paper is first, to indicate a working basis for the classification of forests occurring in the central coastlands, particularly on soils derived from Hawkesbury Sandstones and Wianamatta Shales, and secondly, to discuss the effect of climate and habitat on the distribution of *Eucalyptus* species, and finally to summarize the requirements of individual dominants.

Physiographically, the outstanding feature of the central coastlands is a much dissected Hawkesbury Sandstone plateau which weathers to an extremely poor sandy soil. The plateau extends over an area covered by a wide range of climatic conditions, and provides a variety of topographical habitats. The sandstone is covered by one association, viz., the Mixed *Eucalyptus* Forest Association (Pidgeon, 1937), the uniformity of which is attributable to edaphic conditions, and the many variants of which are determined by climatic and habitat variations. The plateau forms a semi-circle, and partly surrounds an undulating plain of Wianamatta Shales—the Cumberland Basin. This area is not only characterized by an entirely different series of soil types (heavy loams and clays), but it is a low rainfall basin, and is covered by a different type of forest, namely, the *E. hemiphloia–E. tereticornis* Association (Pidgeon, 1937). Outliers of these shales occur on the sandstone plateau under conditions of higher rainfall, both at high and low elevations, and here also the forests are entirely different—they are local expressions of several other associations, one of which is the *E. saligna–E. pilularis* Association (Pidgeon, 1937).

At the outset, there is thus one striking feature, namely, that on Hawkesbury Sandstone, notwithstanding the range of climate, the soil factor is sufficiently predominant to maintain the characteristics of one association throughout the whole area, whereas on Wianamatta Shale, climatic differences of the same order are responsible for the development of several different associations. There is one other noteworthy point, namely, that the dominants in the shale and sandstone forests are strictly segregated; very few species are common to both soil formations (Table 12). The soils are derived from the underlying formations *in situ*, and the boundaries are usually very sharp, but nevertheless the ecotone forests have definite characteristics.

The environmental variants of the central coastlands, such as climate and soil, have been discussed in detail in previous publications of this series. (Pidgeon, 1937, 1938, 1940).

In the classification of forests in this area, there are two sets of major difficulties involved, particularly with reference to sandstone forests:

(i). The large number of tree species, most of which belong to the genus *Eucalyptus*, and which are remarkably sensitive indicators of climatic conditions, particularly of water balance.

(ii). Immature physiography and soils, and consequently a mosaic of micro-climates and habitats.

The combination of these factors results in a bewildering variety of forest stands. In the sandstone forests, pure stands of any one species are not found over wide areas. Mixed stands from two up to as many as six species are typical, but the mixing of the species does not constitute the difficulty so much as the inconstancy of the stands; the species vary with every slight variation in habitat such as slope, aspect, etc. This variation in the mixtures of dominants is undoubtedly one of the most striking features of sandstone forests, and contrasts markedly with the pure stands of conifers, beech or oak, found in parts of U.S.A. and England. Therefore one cannot recognize consociations or consocies as the typical units within the association, and none of the existing nomenclature of the successional analysis of vegetation provides a suitable term to describe these stands of sandstone forests.

Faciation and lociation are the only terms which are at all applicable, but even these are inadequate and unwieldy. It has been suggested (Pidgeon, 1940) that the only suitable method of classification within the association is by forest types,* where "*forest type*" is defined as a forest stand which has, wherever it occurs, the same *floristic composition of dominants*, and which develops in essentially similar habitats. Minor variations in the environment occupied by the association cause this segregation into forest types, and although a forest type may not occupy a large area in any one locality, it constantly occurs in similar habitats. Each forest type occurs as a number of isolated forest stands with the same recurring floristic composition of the dominants. This floristic homogeneity is determined subjectively by observation, and ignores the frequency of the dominants. More detailed analysis of forest stands would doubtless reveal differences among them, both in relative frequency of dominants and in the subsidiary flora.

In the following pages an outline of the classification of forest types occurring on Hawkesbury Sandstones and Wianamatta Shales is given, and more particularly the effect of climate and habitat on the distribution of forest types and of individual species is discussed.

FORESTS ON SOILS DERIVED FROM HAWKESBURY SANDSTONE.

All the forests on Hawkesbury Sandstone belong to the one association—the Mixed *Eucalyptus* Forest. This association is limited to sandy soils, mostly derived from sandstones of the Hawkesbury Series, Newcastle Coal Measures and Upper Marine Series. The greatest extent of this association is in the central coastal area of New South Wales. Various features of the Hawkesbury Sandstone forests have been referred to in previous publications of this series, but the distribution of the dominants throughout the association has not yet been recorded, and apart from the succession studies which refer mainly to the coastal area, no details of habitat requirements of individual tree species have been published. Accordingly in this section, an attempt is made to summarize the general range of dominants throughout the association and the factors controlling this distribution, the effect of climate and habitat on the distribution of individual tree species, and the classification of forest types.

GENERAL RANGE OF DOMINANTS.

The Hawkesbury Sandstones cover an approximate area of 8,000 sq. miles; they extend from the coast up to a distance of more than 100 miles inland, and the altitude ranges from sea level to more than 3,000 ft. Over this area there is a wide range of climate—e.g., the mean rainfall varies from below 30 inches to more than 50 inches (see Pidgeon, 1937, Fig. 1); there is a difference of 10 Fahrenheit degrees between the mean temperatures on the coast at low elevations and inland on the high plateau. At high altitudes on the plateau the mean daily range is approximately twice that occurring on the coast; the winter temperatures at high altitudes are much lower, and frequently snow falls. The difference in length of frost-free period at high and low altitudes is ecologically the most important aspect of temperature.

---

* Pryor (1939) has also successfully classified the vegetation of the Australian Capital Territory by this method.

With such a range of climate, it is not remarkable that many *Eucalyptus* species are restricted in their distribution to parts of the sandstone area; others are "tolerant" species and occur throughout the greater extent of the area—e.g., *E. haemastoma*, *E. micrantha*, *E. eugenioides* and *E. piperita*. This unrestricted extent of at least several dominants is of course one of the criteria by which an association is recognized. The general range of the dominants is indicated in Tables 1 and 3. From an inspection of Table 1 it is evident that there is an altitudinal range of species—e.g., *E. radiata*, *E. goniocalyx*, *E. maculosa* and *E. dives* are restricted to high altitudes, whilst *E. pilularis*, *E. eximia* and others are limited to low altitudes.

TABLE 1.

Distribution of more important dominants of the mixed Eucalyptus *Forest Association on sandstone at low coastal altitudes (about 500 ft.) and at high tableland altitudes (over 3000 ft.). For more complete list, see Table 3. 'x' denotes presence. The order of species in these tables is of no significance.*

Species.	Altitudinal Distribution.	
	High (3000 ft.).	Low (500 ft.).
E. Sieberiana F. v. M.	x	x
E. piperita Sm..	x	x
E. micrantha DC.	x	x
E. haemastoma Sm.	x	x
E. eugenioides Sieb.	x	x
E. gummifera Gaertn.		x
E. punctata DC.		x
Angophora lanceolata Cav.		x
E. pilularis Sm.		x
E. eximia Schau.		x
E. umbra R. T. Baker		x
E. capitellata Sm.		x
E. botryoides Sm.		x
E. radiata Sieb.	x	
E. maculosa R. T. Baker	x	
E. oreades R. T. Baker	x	
E. Blaxlandi Maiden and Cambage	x	
E. goniocalyx F. v. M.	x	
E. dives Schau.	x	
E. rubida Deane and Maiden	x	

In some instances—e.g., *E. oreades** and *E. Blaxlandi*,* altitudinal limitation may be merely a fortuitous floristic distribution, but in general, this is not the case. Nothing is known of the physiology of the various species of *Eucalyptus*, but it is highly probable that for many species limitation to high altitudes may be correlated with a more favourable water balance. Expressing this factor as $\frac{\text{Precipitation}}{\text{Evaporation}}$ (P/E),† the indices for Katoomba (3,349 ft.) and Mt. Victoria (3,490 ft.) on the high plateau of the Blue Mts. are 1·6 and 1·3 respectively, whilst those of Sydney (138 ft.) and Riverview (71 ft.) on the coast

---

* These two species occur only on the Blue Mts. and Moss Vale-Mittagong Tablelands, and on the lower slopes which link these two areas. Both species are typical of high altitudes, but *E. Blaxlandi* descends to 760 ft. at Blaxland, and *E. oreades* to 1,200 ft. at Springwood (both in the Blue Mountain area).

† Data on evaporation are not available except for Sydney, so the P/E index is obtained in the following manner. From percentage mean relative humidity and mean temperature, saturation deficit is obtained from tables; Prescott (1934) has shown that for Australia $\frac{\text{Evaporation}}{\text{Saturation deficit}} = 259$, $\therefore \frac{P}{E} = \frac{P}{\text{s.d.} \times 259}$. For example, Katoomba has a mean relative humidity of 71, and mean temperature of 53·8°F., ∴ saturation deficit (from tables) = 0·13; mean rainfall = 55·1 inches, $\therefore \frac{P}{E} = \frac{55{\cdot}1}{259 \times 0{\cdot}13} = 1{\cdot}64$. This correction factor must be regarded as only approximate, e.g., for Sydney $\frac{P}{E} = 1{\cdot}21$, but using $\frac{P}{\text{s.d.} \times 259}$, it is 1·02.

are 1·02 and 0·89. Conversely, restriction to low altitudes does not necessarily mean that the species are limited to conditions of less favourable water balance (particularly is this not true of *E. pilularis*), but it may mean that they cannot survive the longer period of frosts typical of high altitudes. A scale of susceptibility to frosts, indicated by gradual disappearance at various altitudes, could be represented as in Table 2.

TABLE 2.

Highest recorded altitudes for some of the extra-tableland dominants on sandstone.

Species.	Highest Recorded Altitude (Feet) in Central Coastlands.
E. pilularis	1000
E. eximia	1200
E. punctata	2200
A. lanceolata	2500
E. gummifera	2800

The distribution of some species is apparently controlled by temperature; at least two species, namely *E. Sieberiana* and *E. goniocalyx*, provide evidence of a temperature range. *E. goniocalyx* is found in South Australia and in Victoria, and extends along the coast and tablelands of southern New South Wales, but in the central coastal area it is limited to the high tablelands, and thence continues intermittently at high elevations into northern New South Wales. *E. Sieberiana* extends from Tasmania throughout the coastlands of Victoria and southern New South Wales, and in the central

TABLE 3.

Distribution of dominants of the Mixed Eucalyptus *Forest Association in various regions of the sandstone plateau. For boundaries and climatic features of these sub-regions, see text.* 'x' = *presence*, '·' = *limited occurrence.*

Species.	Regional Distribution.				
	Higher Tablelands. (iv).		Lower Tableland Slopes. (iii) 0–1800 ft.	Coastal. (i) 0–1200 ft.	Macdonald (ii) 800–1000 ft.
	Blue Mts. 2000–3500 ft.	Wingecarribee 2000–2500 ft.			
E. Sieberiana F. v. M.	x	x	x	x	
E. piperita Sm...	x	x	x	x	
E. micrantha DC.	x	x	x	x	x
E. haemastoma Sm.	x	x	x	x	x
E. eugenioides Sieb.	x	x	x	x	x
E. resinifera Sm.		·	x	x	
E. agglomerata Maiden		·	·	·	·
E. gummifera Gaertn.	x		x	x	x
E. punctata DC.		x	x	x	x
E. pilularis Sm.				x	
Angophora lanceolata Cav.	·	x	x	x	x
A. Bakeri C. Hall			·	x	x
E. eximia Schau.			x	x	x
E. umbra R. T. Baker				x	
E. botryoides Sm.				x	
E. capitellata Sm.			x	x	x
E. radiata Sieb.	x	x			
E. maculosa R. T. Baker	x	x			
E. goniocalyx F. v. M.	x	·			
E. oreades R. T. Baker	x	·	·		
E. Blaxlandi Maiden and Cambage	x	·	·		
E. dives Schau.	x	·			
E. rubida Deane and Maiden	·	·			
E. notabilis Maiden	·				
E. Consideniana Maiden	·	·	·		
E. urceolaris Maiden and Blakely		x			
E. fraxinoides Deane and Maiden		x			
Syncarpia laurifolia Ten.			x	x	x

coastlands it is a dominant at high altitudes and in southern localities, but it gradually decreases in importance to the north of the area until it is represented only by a few scattered trees north of the Hawkesbury River. Of the more "tolerant" species, *E. haemastoma*, *E. micrantha** and *E. eugenioides* are widespread and not limited by rainfall or altitude, whereas *E. piperita* becomes scarce at low altitudes with a rainfall of approximately 30 inches, and may be said to be absent from regions receiving less than 30 inches.

The range of dominants throughout the association appears therefore to be governed by the broader aspects of climate, such as effective rainfall, temperature range and length of frost-free period, but the occurrence of any particular species within a restricted area is determined by local habitat conditions. For example, there is a definite spatial zonation from the tops of ridges to the bottoms of gorges; species which are typical of ridges (e.g., *E. haemastoma*) are rarely if ever found on sheltered slopes or gorges. Whether this restriction to less favourable habitats is due to competition or to inability to exist under better environmental conditions has not yet been investigated; for instance, it may be connected with the light factor. However, it has been established that the general restriction of *E. pilularis* to sheltered gorges in sandstone country is correlated with soil moisture conditions—this species grows equally well on the adjacent exposed shale ridges, because soil derived from shale has a greater water-retaining capacity. Small stands of *E. pilularis* are also found on the surface of the coastal sandstone plateau where the rainfall is about 55 inches.

It is possible to group the species occurring in any area according to their typical habitats on ridges and plateau surface, or on slopes and gullies. In the coastal region at low elevations, *E. haemastoma*, *E. micrantha*, *E. gummifera*, *E. punctata*, *E. Sieberiana*, *E. eugenioides* and *E. eximia* are typical of the plateau surface and upper slopes of gorges, whilst *E. piperita*, *Angophora lanceolata*, *E. pilularis* and *Syncarpia laurifolia* are gully types; on the higher tablelands *E. Sieberiana*, *E. piperita*, *E. maculosa* and *E. radiata* occur on the ridges, whilst *E. goniocalyx*, *E. oreades* and *E. Blaxlandi* are typical of more sheltered slopes. Other species have peculiar limitations, e.g., *E. umbra* and *E. botryoides* are confined to the coast not more than a few miles distant from the sea. Distribution of some species may be purely floristic, e.g., *E. urceolaris* has been recorded only in the Wingecarribee sub-region; it is closely related to the widespread *E. piperita*, and may represent a local strain of comparatively recent origin. The distribution of *E. eximia* presents an interesting problem. It occurs very sporadically throughout the coastal region, but is entirely absent from some sections; on the slopes of the tablelands it ascends only to a height of 1200 ft.

The distribution of the dominants outside the Mixed *Eucalyptus* Forest Association on sandstone is noteworthy. A few species are practically restricted to the central coastal area and to soils derived from Hawkesbury Sandstone or to similar sandy soils, e.g., *E. haemastoma*, *E. micrantha*, *E. eximia*, *E. oreades* and *E. Blaxlandi*. Others are very widely distributed coastal species extending from Victoria to Queensland, e.g., *E. pilularis* and *E. gummifera*, which are typical of well drained sandy or loam soils. *A. lanceolata* is widely distributed on poor sandy soils at low altitudes along the coast of New South Wales to Rockhampton in Queensland, and has also found its way to the north-west slopes of New South Wales. *E. piperita* is another species which is practically confined to sandy soils (but not necessarily those derived from Hawkesbury Sandstones). It extends only a short distance north and south of the central coast. *E. punctata* is distributed chiefly in the central coastal area on sandy soils, but extends to drier areas west of the Blue Mts. and in the Upper Hunter Valley. It has also been recorded in south Queensland. The distribution of *E. Sieberiana* and *E. goniocalyx*,

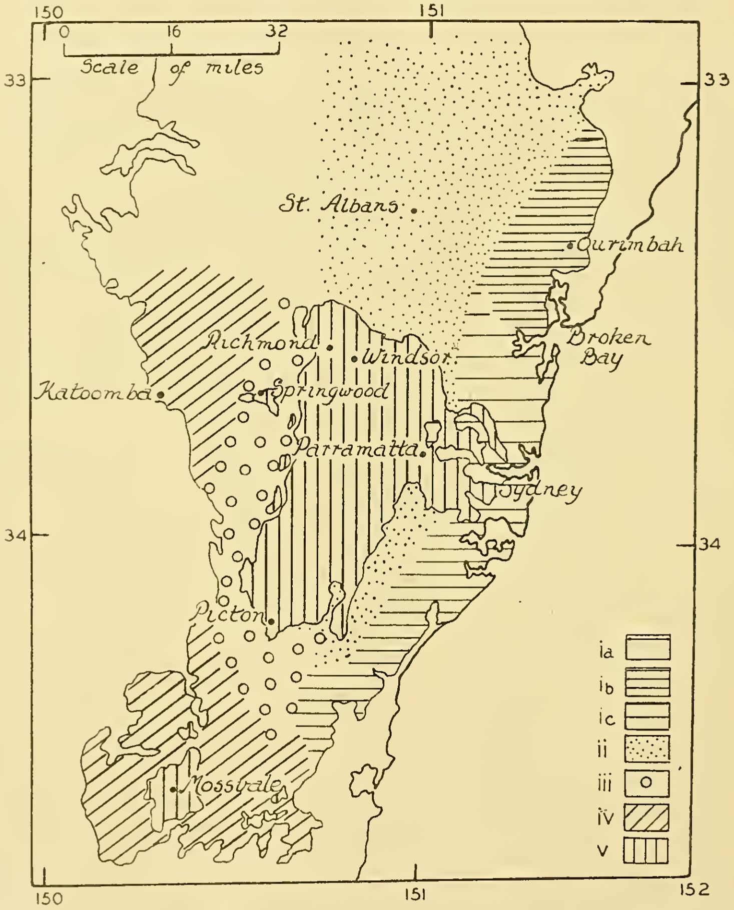
---

* There appears to be some confusion with regard to the distribution of white gums. Blakely records *E. haemastoma* Sm. throughout the entire sandstone area, but does not record *E. micrantha* DC. in the Blue Mountains. He recognizes *E. haemastoma* var. *sclerophylla* Blakely, as a small-fruited form endemic to the Blue Mountains. Although this variety has been recognized by the writer, there appears to be considerable doubt as to the restricted distribution of *E. micrantha*. Accordingly in this paper *E. micrantha* is regarded as having a distribution similar to that of *E. haemastoma*.

which are mainly tableland types, has already been mentioned. *E. radiata*, *E. dives* and *E. maculosa* are found on the tablelands and western slopes of New South Wales; the latter two extend into Victoria. These three species are all typical of sandy soils, but *E. maculosa* also occurs on granite formations. *E. rubida* has an extensive range from Tasmania through South Australia, Victoria, New South Wales and Queensland. In New South Wales it is a high tableland type, and prefers alluvial flats and soils derived from quartz porphyry and granite.

DISTRIBUTION AND HABITATS OF SPECIES, AND CLASSIFICATION OF FOREST TYPES.

The sandstone plateau may be divided into a number of regions* (see Text-figure 1) which differ from one another physiographically and climatically, and consequently are characterized by different groups of forest types. Distribution and habitats of species, and classification of forest types are therefore discussed most conveniently in the various



Text-fig. 1.—Map of central coastlands showing regions and sub-regions of the sandstone plateau [(i) to (iv)] and Wianamatta Shale areas.

(i). Coastal region: (*a*). Hornsby Plateau sub-region, (*b*). Ourimbah sub-region. (*c*). Nepean Ramp.
(ii). Macdonald region.
(iii). Lower Tableland Slopes region.
(iv). Higher Tableland region: (*a*). Higher Blue Mountain Tableland (in vicinity of Katoomba), (*b*). Wingecarribee Tableland (in vicinity of Moss Vale).
(v). Wianamatta Shale.

---

* The writer is grateful to Dr. W. R. Browne, Department of Geology, Sydney University, for his assistance in naming these regions, also for suggesting the term Cumberland Basin.

regions. These are as follows (figures given for altitude and rainfall are only approximate):

(i). The coastal region extending north and south of Sydney, and varying in elevation from sea level to 1200 ft. Mean rainfall is from 40 to more than 50 inches. There are three sub-regions: (*a*) Hornsby Plateau, (*b*) Ourimbah, (*c*) Nepean Ramp.

(ii). The Macdonald region, which includes the country in the vicinity of the Macdonald River, especially the eastern watershed. Average elevation 800–1000 ft.; mean rainfall from less than 30 to less than 40 inches.

(iii). The lower slopes of the tablelands, which include the sandstone valleys in the eastern section of the Blue Mountain Tableland. Elevation from sea level to 1800 ft., and mean rainfall 35 to 40 inches.

(iv). The higher tableland region, which consists of two sub-regions:

- (*a*). The higher Blue Mountain Tableland with an elevation of 2000 to 3500 ft. and mean rainfall 35 to 55 inches.
- (*b*). The Wingecarribee Tableland, which is the area in the vicinity of the Wingecarribee River. This sub-region has sometimes been referred to as the Moss Vale Tableland. The elevation is from 2000 to 2500 ft. and the mean rainfall is from 30 to 40 inches. (Region iii links sub-regions iv*a* and iv*b*.)

Little is known of the sandstone plateau in the vicinity of the Colo River, so discussion of the flora in this region must await further field work. It appears to carry the same type of forest as occurs over parts of region (ii). The outstanding characteristics of the forest flora in these regions are as follows:

Region (i). A number of species is limited to this area, e.g., the strictly coastal forms, *E. botryoides* and *E. umbra*, and the low altitude, high rainfall species, namely *E. pilularis.* Dominants include *A. lanceolata, E. gummifera* (low to intermediate altitude types), and "tolerants" such as *E. haemastoma, E. micrantha, E. piperita* and *E. Sieberiana.*

Region (ii). The composition of the forests differ somewhat from Region (i), because of decreased rainfall. No additional species are present, but trees which were relatively unimportant in region (i) assume dominance, e.g., *E. punctata, E. eximia* and *A. Bakeri,* whilst *E. piperita* rapidly becomes scarce and finally disappears. *E. gummifera* and *A. lanceolata* are also very rare in areas with rainfall of 30 inches.

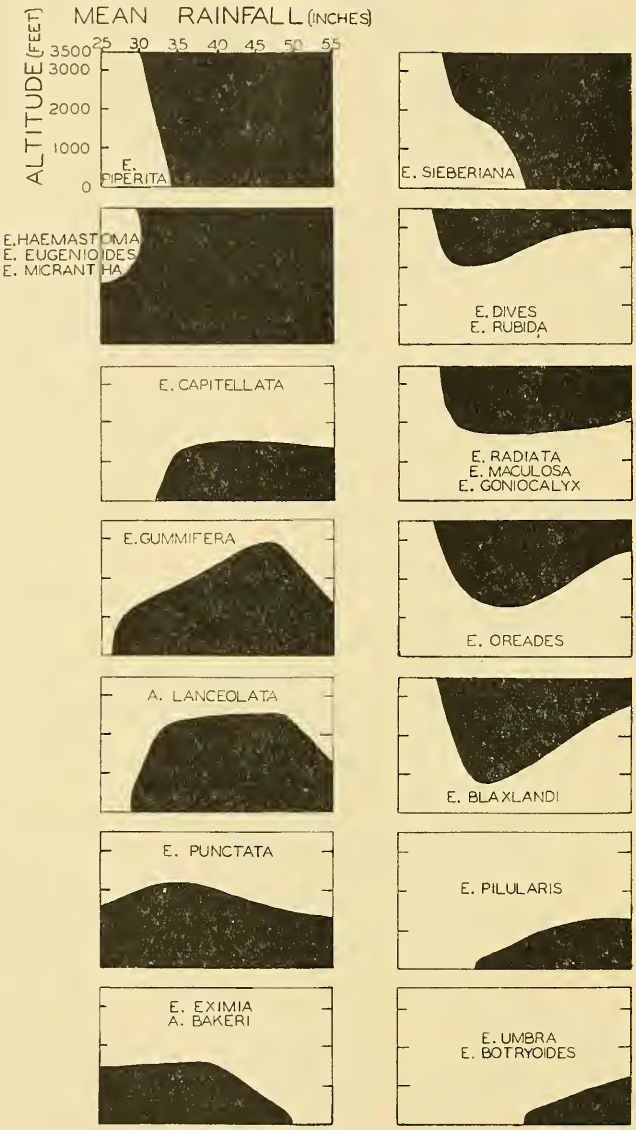
Region (iii). Characterized by a mixture of low altitude species found in regions (i) and (ii).

Region (iv). Species restricted to high altitudes typify this area, e.g., *E. radiata, E. maculosa, E. goniocalyx,* etc.

The distribution of the more important dominants on sandstone, as determined by altitude and rainfall, is shown in the diagrams, Text-figure 2. The most noteworthy point which emerges is the remarkable ecological specificity of the different species of *Eucalyptus.*

(i). *Coastal Region.*

In the coastal region the sandstones extend to the coastline only from south of Port Hacking to Broken Bay. North and south of this area the sandstone scarp flanks narrow coastal plains. The western boundary of this region is taken approximately at the 40 inch isohyet. The coastal region north of Sydney is rugged and presents a complicated pattern of ridges and gorges. It is cut into two sub-regions by the drowned estuary of the Hawkesbury River known as Broken Bay. The southern sub-region is the Hornsby Plateau and in this paper the sandstone area to the north of the Hawkesbury River is referred to as the Ourimbah sub-region. The coastal region south of Sydney (Nepean Ramp) is undulating with extensive drainage areas of upland swamps or moors; there are comparatively few gorges. Conditions for plant growth are more favourable here than on the Hornsby Plateau, where the youthful physiography has resulted in the exposure of a large amount of rock and in the



Text-fig. 2.—Diagrams showing, as blackened areas, climatic tolerance of dominants on soils derived from Hawkesbury Sandstone. There is a correlation between the two variables in the diagrams; for instance, no regions of high altitude and low rainfall fall into the area considered. Accordingly the shape of such a diagram as that for *E. haemastoma* is determined by the peculiarities of the climate, and not by any specificity of the tree species.

constant removal of soil from slopes. On the uplands of the Nepean Ramp the soil has developed comparatively rapidly—the continuous effect of seepage water has resulted in the rotting of the underlying rocks. In addition, the mean rainfall over parts of the Nepean Ramp exceeds 50 inches and mists are frequent. Consequently the forest types differ somewhat from those of the Hornsby Plateau, and are therefore discussed under a separate sub-region.

(*a*). *Hornsby Plateau Sub-region.*

Table 4 contains a list of the more important dominants occurring on the Hornsby Plateau. There are, in addition, a number of relatively unimportant trees of very sporadic occurrence which are limited to sandstone. These are species such as *E. Bottii* Blakely, *E. pseudo-piperita* Maiden & Blakely, *E. Joyceae* Blakely, *E. penrithensis* Maiden, *E. squamosa* Deane & Maiden, *E. deformis* Blakely. A few other species are also found in this area, but they are not typical, e.g., *E. notabilis* Maiden, *E. pellita* F.v.M., etc.

TABLE 4.

Distribution of dominants on sandstone of the coastal region (i) and Macdonald region (ii). 'X' *=most frequently occurring species,* 'x' *=presence,* '·' *=limited occurrence.*

Species.	Distribution.		
	Coastal Region (i).		Macdonald Region (ii).
	Nepean Ramp.	Hornsby Plateau.	
E. piperita	X	X	·
E. haemastoma	x	X	x
E. micrantha	X	X	x
E. gummifera	X	X	x
E. pilularis	x	X	
A. lanceolata	x	X	x
E. Sieberiana	X	·	
E. eugenioides	x	x	X
E. punctata	·	x	X
E. eximia		x	X
E. umbra	x	x	
E. botryoides	x	x	
E. capitellata	x	x	x
A. Bakeri	x	x	X
A. intermedia	·	·	x
E. agglomerata		·	
Syncarpia laurifolia	·	x	x

The following notes contain a brief survey of the habitats of the dominants:

Eucalyptus haemastoma is probably the hardiest sandstone species, and often occupies exposed barren areas to the exclusion of other trees. Occasionally it forms mallee-like thickets. *E. micrantha* is a closely related species which flourishes particularly well in moist or semi-swamp situations on the uplands. *E. gummifera* is a widespread and constant species which occurs over a wide range of habitats from ridges and valleys, and exhibits a variety of habits. These three species may be regarded as characteristic of the plateau surface. *E. piperita* is one of the most typical sandstone species and characterizes slopes. *Angophora lanceolata* is prominent and widespread; it assumes grotesque forms on rocky slopes, but fine specimens are found on lower gully slopes. *E. pilularis* and *Syncarpia laurifolia* are restricted, in this district, to sheltered gullies and slopes where there is a high soil moisture content. *E. punctata** is distributed sparsely over the plateau surface and upper gully slopes. *E. eximia* occurs very sporadically and is absent over extensive areas. Its preference for fairly dry habitats may be emphasized here. *E. eugenioides*† (*E. oblonga* and *E. scabra*) is widespread but sporadic in occurrence. Stringybarks tend to become more numerous on the patches of loam derived from intercalated shale beds and cappings which occur throughout the sandstone. *E. capitellata* is a typical sandstone stringybark of the ridges and uplands. *E. umbra* and *E. botryoides* occur occasionally rather than constantly, their usual habitats being on slopes near the sea. *E. Sieberiana* occurs in restricted areas on the plateau surface, but appears to be infrequent in dry areas. *Angophora intermedia* is only sparsely represented on sandstone (see p. 123) but is almost invariably associated

---

* Blakely (1934) makes a distinction between this species and *E. Shiressii*, but for the purpose of the ecologist they are more satisfactorily regarded as ecological varieties.

† *E. eugenioides* Sieb. has been split into three species by Blakely, viz., *E. oblonga* Blakely (typical of sandstone), *E. globoidea* Blakely (deep shale), and *E. scabra* Dum-Cours (shaly-sandstone). These species are difficult to separate apart from their habitats and accordingly they are grouped under *E. eugenioides* in this paper.

with *E. punctata* and *Casuarina torulosa* on estuarine slopes just above the water level. *A. Bakeri* is sporadic in occurrence and often falls to the rank of a subdominant.

As previously stated, the dominants occur in mixed stands of at least two species. Table 5 has been compiled to illustrate how a classification according to forest types may be made. The extent of the stands listed in the table is usually very limited over any area, because of the broken physiography, but the types constantly recur in similar habitats. In general, it may be said that types 1–6 are characteristic of the ridges and uplands, 7–11 are typical of slopes and sheltered habitats on the uplands, whilst 12–14 are definite gully types, and 15 is practically restricted to estuarine slopes. The recognition of forest types does not take into account any quantitative estimate of the relative proportions of the various dominants, e.g., in type 2 (Table 5), *E. haemastoma* may be more abundant than *E. gummifera*, or *vice versa*, or they may be co-dominant. There are also many variants of these types, e.g., in the *E. piperita–A. lanceolata* type 11, there may be additional individuals of one or more species scattered throughout the stand, e.g., *E. umbra*, *E. eugenioides*, *E. punctata*. The actual composition of a few stands is given below:

TABLE 5.

Some of the more important forest types occurring on the sandstone of the Hornsby Plateau sub-region. Types consisting of pure stands of one species not listed (these are rare).

1. *E. haemastoma—E. micrantha.*
2. *E. haemastoma—E. gummifera.*
3. *E. haemastoma—E. capitellata.*
4. *E. micrantha—E. gummifera.*
5. *E. gummifera—E. capitellata.*
6. *E. gummifera—E. Sieberiana.*
7. *E. gummifera—E. piperita.*
8. *E. Sieberiana—E. gummifera—E. piperita.*
9. *E. piperita—A. lanceolata—E. gummifera.*
10. *E. piperita—A. lanceolata—E. Sieberiana.*
11. *E. piperita—A. lanceolata.*
12. *A. lanceolata—E. pilularis.*
13. *E. pilularis—E. piperita—A. lanceolata.*
14. *E. pilularis—Syncarpia laurifolia.*
15. *E. punctata—A. intermedia.*

A. lanceolata	a*	*A. lanceolata*	a	*A. lanceolata*	a
E. piperita	f*	*E. piperita*	a	*E. piperita*	a
E. umbra	o*	*E. Sieberiana*	r	*E. punctata*	a
E. eugenioides	r*	*E. gummifera*	r	*E. Sieberiana*	f
				E. gummifera	r

Stands which are probably mixtures of two types are also frequent, e.g., *E. haemastoma–E. gummifera–E. piperita* (types 2 and 7). Such types have not been listed in Table 3. Some of the mixed stands indicate successional changes, for example:

E. gummifera	a
E. Sieberiana	f
E. haemastoma	r
A. lanceolata	r

Here, *E. haemastoma* is probably a relict from a more xeric stand of forest, whereas the presence of *A. lanceolata* may indicate improvement of habitat. However, in interpreting any particular stand where successional change is indicated, other evidence must be taken into consideration, e.g., tree girth. In this example, the presence of very old trees of *E. haemastoma* with younger specimens of *A. lanceolata* would lend support to the idea of progressive succession.

(*b*). *Ourimbah Sub-region.*

These forests are much the same as those of the Hornsby Plateau, except that there are very few trees of *E. Sieberiana*, which is here at its northern limit, *E. piperita* is

---

* a = abundant, f = frequent, o = occasional, r = rare.

less frequent but *E. micrantha*, *E. haemastoma*, *A. lanceolata* and *E. gummifera* are abundant. In addition, some *E. pellita* is found, often in association with *E. resinifera* in hollows below the ridges.

(*c*). *Nepean Ramp Sub-region.*

Table 4 summarizes the outstanding differences between the forests of this area and of the Hornsby Plateau. Because of fewer gullies in this sub-region, the *E. pilularis*, *E. piperita* and *A. lanceolata* forest types are less frequent than on the Hornsby Plateau. There is one interesting feature, however, namely, that stands of *E. pilularis–A. lanceolata* are not uncommon on the edge of the plateau overlooking the plain, at an elevation of several hundred feet. This relatively exposed habitat, which is unusual for *E. pilularis* when growing on Hawkesbury Sandstone, is compensated for by an increase of approximately 10 inches mean rainfall when compared with the corresponding topographic habitat on the Hornsby Plateau.

Another noteworthy feature in the Nepean Ramp is the absence of exposed and eroded ridges and consequently the comparative absence of the dry *E. haemastoma* types. *E. Sieberiana*, which in this area has not reached its northern limit, is particularly well represented on the swampy uplands, and frequently is associated with *E. micrantha* on the fringe of the swamps. Various combinations of forest types, including *E. micrantha*, *E. haemastoma*, *A. lanceolata*, *E. Sieberiana*, *E. gummifera*, *E. piperita* and stringybarks are found on the undulating plateau. *E. botryoides* is prominent on the cliffs and scarp overlooking the coastal plain. *E. eximia* is notably absent from this area but occurs further south in the Nowra–Jervis Bay area. The predominantly higher rainfall may acccount for its absence and also for the scarcity of *E. punctata*.

(ii). *Macdonald Region.*

This area is the westward extension of the Ourimbah and Hornsby Plateau sub-regions and is physiographically similar (although it attains higher elevations), but the rainfall is considerably lower and the temperature range greater. The division between this region and the damper more equable coastal region may be taken in the vicinity of the 40-inch isohyet. This region extends as a narrow strip from Parramatta northwards, but broadens considerably north and west of the Lower Hawkesbury River. Floristically the western margin of the Nepean Ramp (west of the 40-inch isohyet) belongs to this area, and also the small outliers of sandstone and exposures in creek cuttings in the Cumberland Basin.

With a mean rainfall of 30–35 inches, the outstanding differences between the forest types here and in regions i*a* and i*b* are (see Table 4): 1. The absence of *E. pilularis* and the infrequency of *E. piperita*, and 2. The increased importance of *E. punctata*, *E. eximia* and *A. Bakeri* and to a lesser extent of all stringybarks. *A. lanceolata*, *E. gummifera*, *E. haemastoma* and *E. micrantha* are still dominants, and *A. intermedia* and *E. paniculata* are locally important.* With a rainfall of less than 30 inches, *A. lanceolata* and *E. gummifera* become rare, and may be altogether absent, whilst *E. punctata*, *A. Bakeri* and *E. eximia* are still the dominants over extensive areas.

The effect of climate on the range of the dominants throughout the coastal and Macdonald regions is summarized in Text-figure 3.

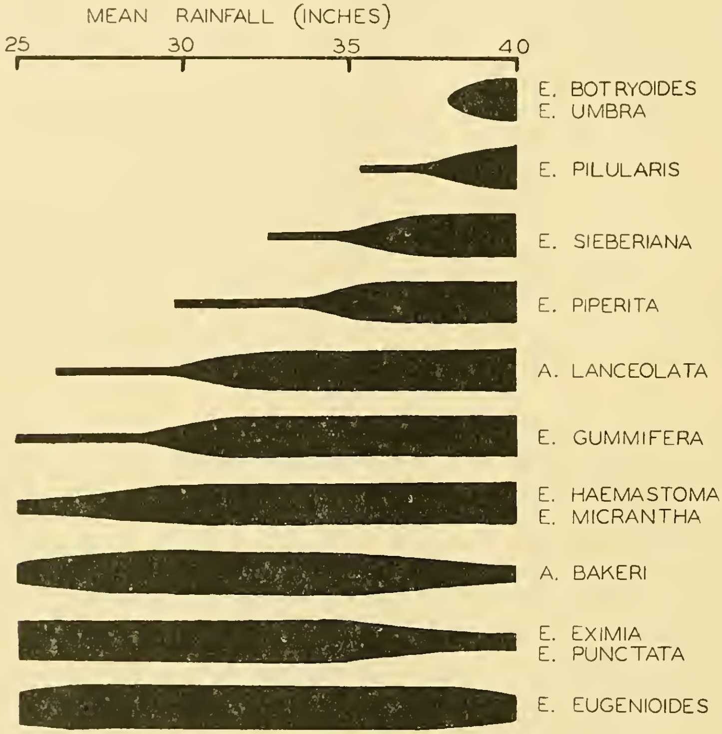
(iii). *Lower Slopes of Tablelands.*

In this area are included the lower slopes and sandstone valleys in the eastern section of the Blue Mt. Tableland up to about Linden (1,700 ft.), the slopes ascending from the southern margin of the Cumberland Basin to the Wingecarribee Tableland about as far as Yerrinbool (1,500 ft.). This region has a fairly good rainfall, averaging 35–40 inches on the Blue Mt. slopes, but decreasing to about 30 inches on the southern slopes near Picton. As far as species are concerned, the lowest slopes of this area (up to about 800 ft.) are analogous to the eastern section of region (ii). On the lower slopes there are no extremes of temperature as on the tablelands, consequently the dominants are species typical of regions (i) and (ii), although two of the tableland species descend

---

* The importance of these species is due to the prominence of shaly bands in the sandstone in this region. (See p. 134, ecotone forests.)

to these lower altitudes. These are *E. oreades*, which has been recorded at Springwood (1,200 ft.) and *E. Blaxlandi* (Blaxland 760 ft.); they are not, however, typical of this area. *E. botryoides*, *E. umbra* and *E. pilularis* are of course absent. The white gums, *E. haemastoma* and *E. micrantha*, are not so evident, probably because the topography is less rugged, whilst it is sufficiently dry for *E. punctata* and *E. eximia* to be well represented. In the sandstone gullies of the Blue Mts. *A. lanceolata*, *E. punctata* and *E. gummifera*, which are absent from the higher altitudes, are frequently occurring species. A list of the more important dominants of this region is given in Table 3.



Text-fig. 3.—Diagram showing effect of decreasing rainfall on distribution of dominants typical of the coastal and Macdonald regions of the sandstone plateau. N.B.: with decreasing rainfall, i.e., increasing distance from the sea, the temperature range becomes greater.

(iv). *Higher Tableland Region.*

The probable correlation between P/E indices and the limitation of many species to high altitudes has been mentioned already. The floristic composition of the forests in the two sub-regions of the tablelands (see Table 6) are slightly different, for example, *E. punctata* is absent and *A. lanceolata* occurs only sporadically up to 2,500 ft. in the Blue Mountain sub-region, whilst *E. gummifera* is absent from the Wingecarribee sub-region. The high altitude species typical of the Blue Mts. such as *E. radiata*, *E. maculosa*, etc., although present in the Wingecarribee, are somewhat localized in their distribution. The absence of *A. lanceolata* and *E. punctata* from the Blue Mts. may be explained by the fact that these species have reached their maximum altitude at approximately 2,500 and 2,200 ft. respectively and are probably restricted from higher altitudes of the Blue Mt. Tableland by the shorter frost-free period. With regard to the less abundant distribution of high altitude species at Wingecarribee, this is most probably connected with P/E

TABLE 6.

Distribution of dominant species on the higher tableland sandstone region of the plateau. 'X' = most frequently occurring species, 'x' = presence, '·' = limited occurrence.

Species.	Distribution. Higher Tableland Region.	
	Wingecarribee.	Blue Mountains.
E. Sieberiana	X	X
E. piperita	X	X
E. micrantha	X	X
E. haemastoma	X	X
E. radiata	x	X
E. maculosa	x	X
E. oreades	x	X
E. dives	·	x
E. Blaxlandi	·	x
E. goniocalyx	·	x
E. eugenioides	x	x
E. rubida	·	·
E. gummifera		x
E. Consideniana	·	·
E. punctata	X	
A. lanceolata	X	·
E. urceolaris	x	
E. fraxinoides	x	
E. agglomerata	·	

index. The Wingecarribee sub-region has a lower rainfall* than the higher Blue Mt. Tableland, and although data are not available for P/E indices in this area, it is more than likely that they would be lower than those given for the Blue Mts. (see p. 115). No explanation can be given for the absence of *E. gummifera* from the Wingecarribee sub-region; it is still present at Wentworth Falls (Blue Mts.) at an elevation of 2,800 ft. In these high plateaux a number of species typical of other associations occur sporadically—the western section of the Blue Mts. is in the nature of a meeting ground for the sandstone species and those typical of the forests on the cool western slopes.

(*a*). *Higher Blue Mountain Tableland.*

The rainfall in this sub-region decreases gradually to the north-west, so that from Katoomba (3,336 ft.), with a mean rainfall of 55 inches, it decreases at Mt. Victoria (3,424 ft.) to 37·5 inches. This is reflected to some extent in the forests; for example of the "peppermints", *E. piperita* prefers the moister eastern slopes whilst *E. dives* prefers the drier western section.

The species typical of the higher Blue Mt. Tableland are listed in Table 6. There is a topographical restriction of the various species, which, however, is not so well marked as in the coastal plateau, because in the central† and western sections of the Blue Mountains the rivers have cut through the sandstone of the Hawkesbury and Narrabeen Series, and have their valley floors either in the soft shales of the Coal Measures, Upper Marine Series, or in older rocks, e.g., granites. In these canyons and gorges there are different *Eucalyptus* forest associations, as well as patches of marginal sub-tropical rain-forest. However, Hawkesbury Sandstones form the surface of the plateau, and there is a variety of habitats from windswept cliffs to sheltered high valleys and slopes. *E. Sieberiana*, *E. piperita*, *E. maculosa* and

---

* Mean rainfall.—Mittagong 32·7, Moss Vale 38·8, Sutton Forest 35·5, Bundanoon 42, whereas over the greater part of the Blue Mts. it is at least 45, and frequently more than 50 inches. This higher available moisture in the Blue Mts. is further emphasized by the following fact: the composition of the Hawkesbury Sandstones west of Lawson (Blue Mts.) appears to be somewhat different from much of the typical siliceous sandstone in that there is an increase in felspathic material, which increases the water-retaining capacity of the soil. This seems to be related to the nearness of granitic source of supply from the west.

† Most of the eastern section of the Blue Mts., in which sandstone extends to the base of the gorges, is included in region (iii).

E. micrantha are abundant on the tops and ridges of the plateau throughout a considerable area: *E. radiata* is common on the highest parts whilst *E. gummifera* occurs only at elevations below 3,000 ft. *E. oreades* and *E. goniocalyx* prefer the sheltered slopes, and in these habitats *E. viminalis* is sometimes found. The stringybarks *E. Blaxlandi* and *E. eugenioides* are abundant both on slopes and ridges. Among the less frequent species are *E. Consideniana*, and in the drier western section of the mountains, *E. dives* and *E. rubida*.

There are many unimportant species of sporadic occurrence which have not been listed; these include *E. notabilis* Maiden, *E. stellaris* Blakely, *E. petrophila* Blakely, *E. Bauerleni* F.v.M., *E. montana* Blakely and *E. squamosa*. With the exception of *E. squamosa* which is also found on the coastal region, these species are all practically restricted to sandstone of the Blue Mts., and may therefore be floristically peculiar to this area. There are also many other unimportant species which have been recorded as occurring sporadically in the Blue Mts., some of which occur on other soil formations or in other regions, e.g., *E. aggregata* Deane and Maiden, *E. mannifera* Mudie, *E. nigra* R. T. Baker, *E. elaeophora* F.v.M. and *E. agglomerata* Maiden.

The forest types of this sub-region are too numerous to list, but as an example of the variety encountered, the following are some of the types recorded in the Leura–Katoomba districts: *E. Sieberiana* (pure); *E. micrantha* (pure): *E. oreades* (pure); *E. Sieberiana–E. radiata–E. piperita*; *E. Sieberiana–E. piperita–E. maculosa–E. micrantha*; *E. goniocalyx–E. Blaxlandi–E. eugenioides*; *E. oreades–E. goniocalyx*; *E. oreades–E. piperita–E. Sieberiana*; *E. maculosa–E. radiata–E. oreades*.

(*b*). *Wingecarribee Sub-region.*

The most typical species occurring in this section are listed in Table 6. *E. Sieberiana*, *E. piperita*, *E. punctata*, *E. micrantha* and *E. eugenioides* are the most frequent dominants; *E. radiata* and *E. maculosa* are also common but somewhat localized in their distribution. Other dominants typical of the Blue Mts. such as *E. oreades*, *E. Blaxlandi* and *E. goniocalyx* are present, but not widespread. An important species which is floristically peculiar to this area is *E. urceolaris*. This plateau is also the only sandstone area where *E. fraxinoides* occurs; this species is at its northern limit here and extends south to the tablelands near the Victorian border. Of occasional occurrence are *E. dives* and *E. rubida*, whilst *E. Consideniana*, *E. Wilkinsoniana*, *E. agglomerata*, *E. aggregata* and *E. mannifera* occur very sporadically. A few unimportant species which are also found on other soils and in other associations in this region but which do not occur elsewhere on sandstone are *E. Callanii*, *E. vitrea* and *E. cinerea*.

DISTRIBUTION OF MALLEES.

The dwarf species of *Eucalyptus*, known as mallees, are typical of exposed areas, and are particularly characteristic of extensive areas of windswept plateau along the edges of cliffs in the higher Blue Mt. Tableland. In the coastal region, mallees occur sporadically and in small group societies, but do not form extensive areas of tree-scrub. The distribution of the various species of mallees, like that of the dominants, falls into two fairly well-defined groups characteristic of the low coastal region and the higher tablelands; several species, e.g., *E. stricta* and *E. multicaulis*, are not limited by altitude and occur throughout the association. The specific range is summarized in Table 7. In the coastal region *E. virgata*, *E. obtusiflora* and *E. multicaulis* are the most prominent mallees, but in the Blue Mts. *E. stricta* is the most frequent species.

Forests on Soils Derived from Wianamatta Shales.

Most of the Wianamatta Shales occur in a basin-like area to the west of Sydney, referred to as the Cumberland Basin. The plains are gently undulating with low hills up to 500 ft. The physiography of this area has resulted in the preservation of these soft shales which, except for a few shallow outliers, have been eroded from the surrounding sandstone plateau. Three stages of the Wianamatta Shales are recognized. These are: 1. Upper stage, consisting mainly of sandstone with interbedded shales. 2. Middle stage, containing the calcareous ostracod sandstones. 3. Lower stage, consisting exclusively of shales. Over most of the Cumberland Basin the upper stage

TABLE 7.

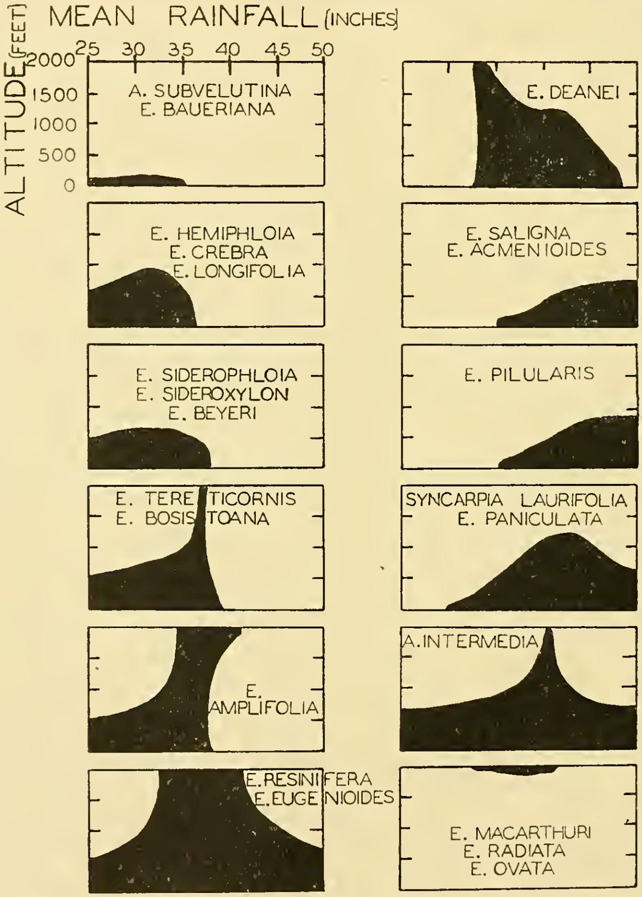
Distribution of mallees in the various regions of the sandstone plateau. 'x' denotes presence.

Species.	Distribution.				
	Coastal Region.			Higher Tableland Region.	
	Hornsby Plateau.	Ourimbah.	Nepean Ramp.	Blue Mountains.	Wingecarribee.
E. virgata Sieb.	x	x	x		
E. obtusiflora DC.	x	x	x		
E. Camfieldi Maiden	x	x	x		
E. multicaulis Blakely	x	x		x	
E. deformis Blakely		x		x	
E. pygmaea Blakely	x				
E. stricta Sieb.	x	x		x	x
E. apiculata Baker and Smith				x	x
E. triflora Blakely				x	
E. ligustrina DC.				x	
E. rigescans Blakely				x	
E. aequans Blakely				x	
E. tephrophloia Blakely				x	

has been eroded but parts of the middle stage have been preserved, and where the ostracod sandstones outcrop to any extent they have been utilized for vineyards. In the Parramatta–Windsor districts in the Cumberland Basin, the lower stage only remains, and the various shale outliers on the sandstone plateau are also formed entirely of these lower beds. Apart from the ostracod sandstones, which cover a relatively small area, the soils derived from the various shale horizons are therefore comparable. Small amounts of ostracod sandstones have little or no effect on the type of forest developed, but it is interesting to record that in the Kurrajong–Grose Vale districts on calcareous sandstones, remnants of "brush" or marginal rain-forest are found. The soil is probably not entirely responsible for this, because the area receives a high rainfall—approximately 50 inches, and is also relatively sheltered.

The Cumberland Basin corresponds approximately to a low rainfall area with a mean rainfall of less than 30 inches; the P/E index for Richmond, which is typical of the area, is 0·63 (cf. Sydney 1·02), whilst that of Parramatta on the eastern margin of the basin is 0·76. As well as being comparatively dry, this region is also hot with extremes of temperature—mean daily range at Richmond is 25 Fahrenheit degrees, whereas the range at Sydney is 14 Fahrenheit degrees. Shale soils under these climatic conditions are covered by the *E. hemiphloia–E. tereticornis* Association, but with an increase in mean rainfall up to approximately 38 inches this association is replaced by entirely different forests. The only Wianamatta Shale soils receiving this higher rainfall occur as outliers on the sandstone plateau. There are three distinct groups of outliers: (Text-fig. 1) (*a*) on the Hornsby Plateau, (*b*) on the lower slopes of the Blue Mts., (*c*) on the Wingecarribee Tableland in the vicinity of Moss Vale. In district (*a*) the *E. saligna–E. pilularis* forest types occur, and in district (*b*) forest types consisting of *E. Deanei*, *Syncarpia*, *E. paniculata* and *E. eugenioides* are present. All these forest types belong to the *E. saligna–E. pilularis* Association. In district (*c*) a different set of forest types consisting of *E. radiata–E. eugenioides–E. goniocalyx*, *E. Macarthuri–E. ovata*, and *E. pauciflora–E. stellulata* are present. These types are fragments of several different associations.

The most probable factor which determines the delimitation of these associations is P/E index. With an index of < 1 (approximately 0·6), the *E. hemiphloia–E. tereticornis* Association is present; with an index of approximately 1, the *E. saligna–E. pilularis* forest replaces the former. This association, however, does not occur at high altitudes, e.g., at Moss Vale, because both dominants are low altitude species, probably limited by length of frost-free period. Hence new forest types make their appearance, namely, *E. radiata*, *E. goniocalyx*, *E. Macarthuri*, *E. ovata*, *E. pauciflora*, etc. An attempt has been made to represent the climatic control of the distribution of the dominants on shale soil in Text-figure 4. In Table 8 are listed all the important species occurring on the various outcrops of Wianamatta Shale in the central coastlands. There are a few species common to both the *E. saligna–E. pilularis* and *E. hemiphloia–E. tereticornis* Associations but the dominants from which these associations derive their names are segregated from one another; this justifies their separation as associations (Pidgeon, 1937); the forests of the cold tablelands have little in common with either of the other associations. In the following pages the various forest types and associations found on Wianamatta Shales are discussed in more detail. Apart from the *E. hemiphloia–E. tereticornis* Association, the other forest types are very limited and are recorded here only as an example of the dominating influence of climate on the development of different forest associations on the same geological formation.



Text-fig. 4.—Diagrams showing tolerance of dominants on soils derived from Wianamatta Shales.

E. hemiphloia–E. tereticornis *Association.*

As previously stated, this association is typical of soils derived from Wianamatta Shales with a rainfall of 30 inches or less. Other fragments of this association occur in dry areas along the coast of New South Wales, e.g., at Dapto (in the south of the central coastal area) and in the Upper Williams River (Fraser and Vickery, 1939).

Physiognomically, the *E. hemiphloia–E. tereticornis* Association has more affinity with woodland than typical coastal forest formation. The parkland appearance has been further emphasized by timber cutting for firewood (especially of *E. hemiphloia*) and clearing for cultivation.

TABLE 8.

List of more important dominants occurring on Wianamatta Shale soils in various sub-regions of the central coastlands. 'X'=most frequently occurring species, 'x'=presence, '·'=limited occurrence.

Species.	Distribution. Cumberland Basin.	Hornsby Plateau.	Wingecarribee.	Lower Tableland Slopes.
E. hemiphloia	X			
E. tereticornis	X		·	
E. siderophloia	X			
E. sideroxylon	x			
E. crebra	X			
E. Beyeri	x			
E. longifolia	x			
E. amplifolia	X		x	
Angophora intermedia	X	x	·	·
A. subvelutina	X			
E. eugenioides	x	x	x	x
E. resinifera	·	x	·	x
E. maculata	·			
E. Baueriana	·			
E. Rudderi	·			
E. Parramattensis	·			
E. Macarthuri			X	
E. ovata			X	
E. radiata			X	
E. goniocalyx			X	
E. stellulata			·	
E. pauciflora			·	
E. paniculata	·	x		x
E. saligna		x		
E. pilularis		x		
E. acmenioides		x		
Syncarpia laurifolia	·	x		X
E. Deanei	·		·	X

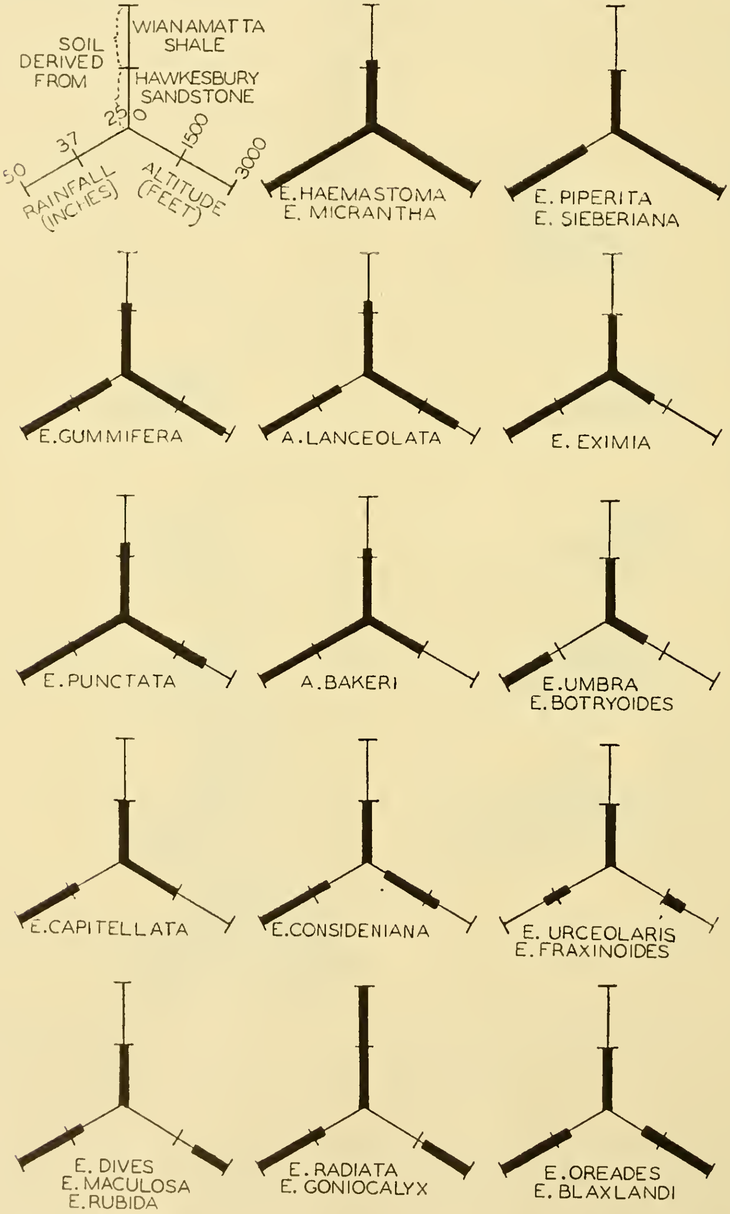
TABLE 9.

List of dominants in the E. hemiphloia–E. tereticornis *Association.* '*'=*most frequent species.*

**E. hemiphloia* F. v. M.
**E. tereticornis* Sm.
**E. amplifolia* Naudin.
**E. siderophloia* Benth.
**E. sideroxylon* (A. Cunn.).
**E. crebra* F. v. M.
**E. Beyeri* R. T. Baker
**A. intermedia* DC.
**A. subvelutina* F. v. M.
**E. eugenioides* Sieb.
E. longifolia Linn. and Otto.
Syncarpia laurifolia Ten.
E. resinifera Sm.
E. paniculata Sm.
E. sparsifolia Blakely.
E. Wilkinsoniana R. T. Baker.
E. acervula Sieb.
E. maculata Hook.
E. Parramattensis C. Hall.
E. Bosistoana F. v. M.
E. Baueriana F. v. M.
E. Rudderi Maiden.
Melaleuca spp.
Casuarina Cunninghamiana (near fresh water).

The more important tree species of this association are listed in Table 9. The habitats available to these species are not so very diverse since the shale country is gently undulating; there are, however, extensive flats which are liable to flooding and waterlogging. Brief notes on the habitats of some of the more important species are given below:

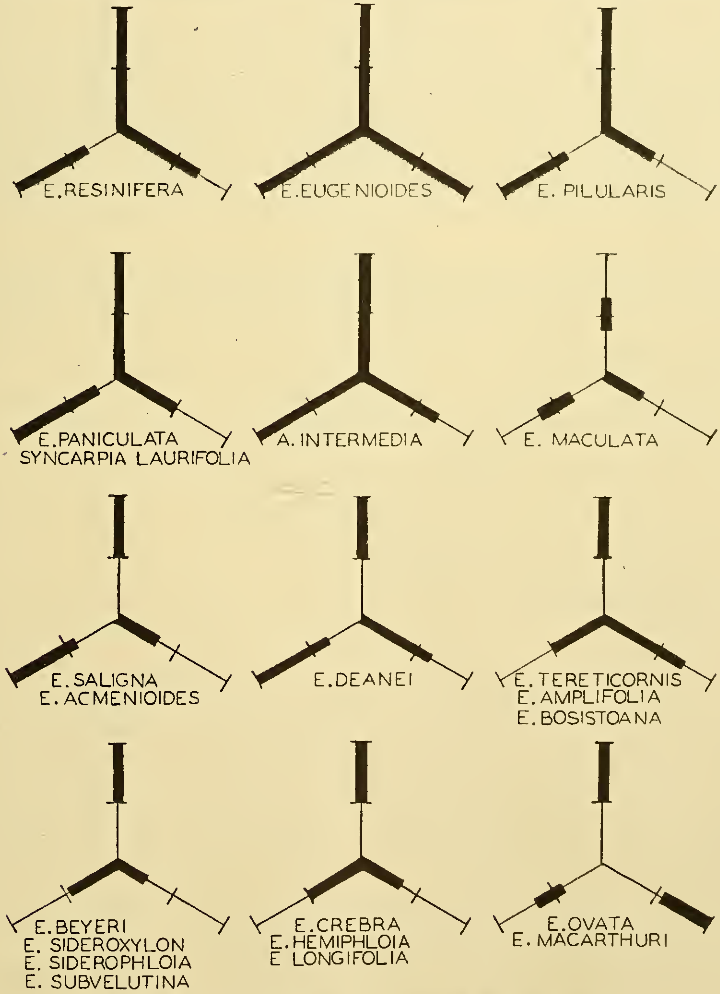
E. hemiphloia and *E. tereticornis* are the most widespread species. They prefer well-drained soils of the slopes, but are not altogether absent from the flats. *E. amplifolia* is very similar to *E. tereticornis* and replaces it on swampy flats in the vicinity of creeks. The ironbarks *E. siderophloia*, *E. crebra* and less commonly *E. Beyeri*, *E. paniculata* and *E. sideroxylon*, occur on low ridges and hillsides, the soil often being lateritic gravel. *E. siderophloia* also extends to the flats. *E. paniculata* is more or less restricted to the margins of the Cumberland Basin, i.e., in the higher rainfall areas. *Angophora intermedia* is another widespread species, whilst *A. subvelutina* is limited to heavy soils on the flats. *E. eugenioides*, *E. resinifera*, other stringybarks and *E. longifolia* occur scattered throughout the whole area, usually on well-drained soils. There is a number of additional unimportant species of limited occurrence, e.g., *E. Baueriana* and *Casuarina Cunninghamiana*, which are restricted to creek banks, and *E. Bosistoana* and *E. Rudderi*. Small patches of *E. maculata* occur in isolated localities, usually on soil derived



Text-fig. 5*a*.—Diagrams showing edaphic and climatic tolerance of the more important species occurring on soils derived from Hawkesbury Sandstones and Wianamatta Shales. The distribution of species peculiar to edaphic ecotones is represented as in the diagram for *E. maculata*, and that of species peculiar to one particular soil type, but which also occur in ecotones, is represented as in the diagram for *A. lanceolata*.

from a mixture of sandstone and shale. The presence of subdominant strata of *Melaleuca* spp. (e.g., *M. styphelioides, M. linariifolia*) indicates occasional waterlogging of the soil.

The wider distribution of the more important dominants outside the *E. hemiphloia–E. tereticornis* Association is noteworthy. *E. hemiphloia* occurs in the drier parts of the central and northern coast of New South Wales and extends into Queensland. It is typical of heavy soils or light soils with clay sub-soil, rather low-lying and more or less subject to waterlogging. *E. tereticornis* is a coastal species extending from Victoria along the east coast of Australia. It has its best development on the flats on fairly rich soils. *E. amplifolia* extends further inland than *E. tereticornis*, but occurs only in New South Wales and Queensland. It is confined to shallow alluvial flats of heavy soils. *E. siderophloia* is chiefly coastal in its distribution and extends from the central coast of New South Wales to Rockhampton. It occurs on a variety of soils from sub-basaltic to poor sandy flats with hard clay sub-soil. *E. sideroxylon* extends from Victoria to Queensland and in New South Wales is more frequent on the western slopes where it favours Silurian slate ridges. It also occurs on the coast on poor sedimentary formations. *E. crebra* extends from the central coastlands of New South Wales to Queensland; it is not a coastal species, but flourishes under hot



Text-fig. 5*b*.—For explanatory details see Text-fig. 5*a*.

dry conditions. *E. Beyeri* is restricted to the shales of the Cumberland Basin. *E. paniculata* is a strictly coastal species extending along the coast of New South Wales and Queensland. It occurs mainly on shale and sandy-loams. *Angophora intermedia* and *A. subvelutina* extend from the central coast to Queensland. The former is widely distributed in the central and north-west slopes of New South Wales on alluvial and deep sandy soil, along flats and watercourses, and extending up hillsides. *A. subvelutina* is more coastal in distribution, and occurs on heavy, moderately rich soils, almost always near watercourses. *E. maculata* is distributed along the eastern coast of Australia on a wide range of soil types, but usually on moderately poor sandy-shales. In the central coastlands it frequently occurs on Narrabeen Shales. *E. longifolia* is chiefly distributed along the south and central coasts of New South Wales on deep alluvial soil.

No attempt is made to list all the forest types in the *E. hemiphloia–E. tereticornis* Association, but an indication of the variety of types found in one small area is given in Table 10. In addition to mixed stands, fairly pure stands of species such as *E. hemiphloia*, *E. crebra* and *E. siderophloia*, and co-dominant types such as *E. hemiphloia–E. siderophloia* and *E. tereticornis–E. hemiphloia* are of wide occurrence.

E. saligna–E. pilularis *Association.*

The *E. saligna–E. pilularis* Association is extensively distributed over the coastal plains of New South Wales, and in the central coastal area is typical of Narrabeen Shales and of some of the soils derived from the Upper Coal Measures. This paper is concerned only with its occurrence on the Wianamatta Shale outliers on the Hornsby Plateau, and on the lower slopes of the Blue Mts. On the Hornsby Plateau these outliers form two parallel divides, one of which separates the deep valleys of Middle Harbour and the Lane Cove River, and the other to the west links up with the shales of the Cumberland Basin (see Fig. 1).

TABLE 10.

Some forest types of the E. hemiphloia–E. tereticornis *Association recorded in the Bankstown–Liverpool districts. Species in braces indicate those which may occur as subsidiary species in that particular forest type.*

E. siderophloia–E. hemiphloia ±	*E. tereticornis* *Syncarpia laurifolia*
E. hemiphloia–E. tereticornis.	
E. hemiphloia–E. tereticornis–E. crebra ±	*E. eugenioides* *E. longifolia* *E. siderophloia*
E. tereticornis–Angophora intermedia.	
A. intermedia–E. longifolia–E. tereticornis ±	*E. eugenioides* *E. sideroxylon*
E. paniculata–E. tereticornis ±	*E. longifolia* *E. siderophloia*
E. tereticornis–E. sideroxylon–E. crebra.	
E. crebra–E. siderophloia.	
A. subvelutina–E. amplifolia.	

Since the shale outliers occupy ridges, they are for the most part fairly exposed, but there are shallow valleys and hollows which give protection. Whereas on sandstone these shallow valleys would result in a complete change in forest type from that on the ridge, because constancy of forest type is dependent on soil moisture conditions, and these vary with slope, on shale the same dominants (namely *E. saligna* and *E. pilularis*) occur in both habitats. This is explained by the fact that shale soils have a sufficiently high water-retaining capacity to enable the forest type to be independent of minor changes in environment. It is noteworthy, however, that with protection in the hollows, a number of mesophytic species occur in the sub-dominant strata.

Species which represent the association on Wianamatta Shale are: *E. saligna*, *E. pilularis*, *E. paniculata*, *E. acmenioides*, *E. resinifera*, *E. eugenioides*, *Angophora intermedia* and *Syncarpia laurifolia*. *E. saligna* and *E. acmenioides* occupy the moist habitats usually to the exclusion of other species, whilst *E. pilularis* and *E. paniculata*, in addition to *E. saligna*, occur on the drier slopes. The forest types are mainly variants of *E. saligna–E. pilularis* and *E. pilularis–E. paniculata–Syncarpia* groupings.

On the shales to the east and north of Parramatta there is an ecotone in which *E. pilularis*, *E. saligna* and *E. tereticornis* are intermingled. The transition from the *E. saligna–E. pilularis* Association (rainfall 40 inches) to the *E. hemiphloia–E. tereticornis* Association (rainfall 30 inches) is illustrated by Table 11.

TABLE 11.

Transect from Parramatta to Windsor, along the Windsor Road. (See Text-fig. 1.)

Approx. Mileage.	District.	Mean Rainfall. (Inches.)	Dominant Species.	Additional Notes.
0 4½	Parramatta to Baulkham Hills.	35	*E. paniculata.* *E. pilularis.* *E. saligna* (on flats near creeks). *A. intermedia.* *Syncarpia laurifolia.* *E. acmenioides.* *E. punctata.* Various stringybarks.	*E. tereticornis* and *E. crebra* occur sporadically.
7 9	Seven Hills to Kellyville.	30 (approx.)	*A. intermedia.* *E. tereticornis.* *E. siderophloia.* *E. hemiphloia.* *E. crebra.* *E. eugenioides.* *E. saligna.*	*E. saligna* still abundant on flats. First appearance of *E. hemiphloia.*
9 13	Kellyville to Rouse Hill.	—	*E. crebra.* *E. siderophloia.* *E. tereticornis.* *E. amplifolia* } creeks. *A. intermedia* } creeks.	*E. saligna* occasional on flats.
15	Riverstone turn-off.	—	*E. crebra.* *E. siderophloia.* *E. tereticornis.* *E. hemiphloia.* *E. amplifolia* } creeks. *Casuarina Cunninghamiana* } creeks.	*E. saligna* disappears, *E. hemiphloia* abundant.
21	Windsor.	27	*E. tereticornis.* *E. hemiphloia.* *E. crebra.* *E. siderophloia.*	
28	Lower slopes Grose Vale road.	More than 35	*Syncarpia laurifolia.* *E. tereticornis.* *E. crebra* (on hills).	*E. hemiphloia* disappears; greater rainfall and well drained slopes.

On the lower slopes of the Blue Mts., e.g., at Springwood, there is a number of small scattered outliers of shale. Neither *E. saligna* nor *E. pilularis* occurs in these areas, but *E. Deanei* is present. This species appears to replace *E. saligna* at higher altitudes and inland from the coastal area. Other species which are present include *Syncarpia laurifolia*, *E. paniculata*, *E. eugenioides* and *E. resinifera*. These small stands of forest may be regarded as local variants of the *E. saligna–E. pilularis* Association.

Forest Types on the Wingecarribee Tableland.

The Wianamatta Shales in the Bundanoon–Moss Vale–Bowral area are characterized by an entirely different set of forest types, viz., *E. Macarthuri–E. ovata* on flats near watercourses; *E. radiata–E. goniocalyx–E. eugenioides* and *E. pauciflora–E. stellulata* on well-drained areas. Additional species of minor importance include *E. viminalis*, *E. amplifolia*, *Angophora intermedia*, *E. tereticornis* and *E. Bosistoana* (rare). So that, apart from *E. eugenioides* and *E. amplifolia*, and a few odd trees of *E. tereticornis*, *A. intermedia* and *E. Bosistoana*, this shale vegetation bears no relationship to the two preceding associations. The differences might be attributable to climate, which is of the cold tableland type with severe frosts.

The affinities of the various forest types are suggested as follows:

(*a*). *E. radiata–E. goniocalyx–E. eugenioides* forest types: allied to the *E. viminalis–E. fastigata* Association (including *E. obliqua*). This is a wet sclerophyll type of forest characteristic of the southern tablelands of N.S.W.

(*b*). *E. pauciflora–E. stellulata* type: a fragment of the association of the same name, also typical of southern tablelands at high elevations.

(*c*). *E. amplifolia*, *E. tereticornis*, *E. Bosistoana*: scattered trees representing outliers of the *E. hemiphloia–E. tereticornis* Association.

(*d*). *E. Macarthuri–E. ovata*: subclimax types controlled by drainage.

SANDSTONE AND SHALE ECOTONES.

Since there is every gradation between shale and sandstone around the outliers of shale, one would expect, and one does find transitional zones (ecotones). Most of the transitional forests have two features in common, first a mingling of dominants from both soil types, and secondly, a peculiarly characteristic undergrowth which can be distinguished from that typical of sandstone forests by the absence of a large number of sclerophyllous shrubs and an increase in the number of grasses and herbs. The actual composition of any stand of transitional forest is dependent on the depth of shale and on the soil moisture. A brief summary of some of the more frequent ecotone forests is recorded in the following notes:

Ecotones between the E. saligna–E. pilularis *and Mixed* Eucalyptus *Forest Association.*

These ecotones contain a predominance of stringybarks (*E. resinifera* and *E. eugenioides*), with *Syncarpia laurifolia*, *E. paniculata*, *E. pilularis* and *A. lanceolata*. Notable absentees are *E. saligna*, *E. piperita* and *E. haemastoma*. The composition of the stands varies according to the depth of shale. On thin cappings *A. lanceolata*, *E. gummifera* and *E. micrantha* may occur with scattered trees of *E. eugenioides*, *E. pilularis* and *Syncarpia*. On deeper shale transitions, *E. resinifera*, *E. eugenioides*, *E. pilularis*, *Syncarpia* and *E. paniculata* are the dominants.

Ecotones between the E. hemiphloia–E. tereticornis *and Mixed* Eucalyptus *Forest Associations.*

These ecotones are abundant and variable and since they occur in the vicinity of the 30 inch isohyet, the sandstone species are those typical of the drier areas. The constituent trees of ecotone forests in four localities are listed below:

Bankstown.	The Oaks: Camden.	Bargo.	Campbelltown-Appin.
E. eugenioides.	*Syncarpia laurifolia.*	*E. paniculata.*	*E. maculata.*
A. intermedia.	*A. lanceolata.*	*E. punctata.*	*E. eugenioides.*
E. punctata.	*E. punctata.*	*E. micrantha.*	*E. paniculata.*
Syncarpia laurifolia.	*A. intermedia.*	*E. eugenioides.*	*E. crebra.*
E. paniculata.	*E. resinifera.*		
	Various ironbarks and stringybarks.		

Ecotone Forests on Soils derived from Shale Bands in Hawkesbury Sandstone.

A number of relatively small lenticular shale beds are intercalated throughout the Hawkesbury Sandstone strata, and these weather to a slightly better soil than that derived from pure sandstone. These shale bands are particularly evident throughout parts of the Macdonald region, especially around the Upper Colo district, and on the loams derived from a mixture of these shales and sandstones occur species such as *E. paniculata*, *A. intermedia*, *Syncarpia*, and various stringybarks. These species are associated with other typical sandstone species such as *E. punctata*, *A. lanceolata*, and

E. gummifera. Similar shale bands of lesser extent occur throughout the coastal region, but here *A. intermedia* is less evident; it apparently prefers the drier areas. Where these shale beds are very thin they do not greatly improve the water-retaining capacity of the soil, and the forest may consist entirely of sandstone species such as *E. micrantha, A. lanceolata, E. eugenioides* and *E. gummifera,* but the stands are better developed than those on similar positions on pure sandstone soils.

CONCLUSIONS.

Any classification of vegetation is subjective, and must stand or fall by its accordance with current ideas on the structure of plant communities, and on its convenience to foresters and ecologists. The major difficulty in classifying the forests described in this paper is that many species of *Eucalyptus* are not only taxonomically but ecologically distinct. The data assembled in Text-figures 2, 3, and 4 illustrate how there is a group of Eucalypts adapted to every complex of conditions, and very few species are tolerant of a wide range of conditions. It is difficult, therefore, in an area with a great assortment of micro-climates, to avoid an unwieldy classification. Yet it is clear from the results of Scandinavian plant geographers that one must avoid the temptation to split up communities without good reason. Lindquist, for instance (1931), distinguishes thirteen different associations of an herbaceous plant *Asperula,* according to the species associated with it; and Osvald (1923), following the same course, discovers 164 separate associations in a stretch of moorland only forty square miles in area. On the criteria used by these workers hundreds of associations could be described among the forests around Sydney. Each of the *Angophora lanceolata* forest

TABLE 12.

Table showing specific effect of soil on species distribution in the central coastlands. ' x ' =*presence,* ' x′ ' =*presence in Wingecarribee sub-region only,* ' · ' =*limited occurrence.*

Species.	Distribution on Soils Derived from			Species.	Distribution on Soils Derived from		
	Hawkesbury Sandstone.	Wianamatta Shale.	Ecotones.		Hawkesbury Sandstone.	Wianamatta Shale.	Ecotones.
E. Sieberiana	x			*Syncarpia laurifolia*	x	·	x
E. piperita	x			*E. paniculata*		x	x
E. micrantha	x			*E. agglomerata*	·		·
E. haemastoma	x			*A. intermedia*	·	x	x
E. gummifera	x			*A. subvelutina*		x	
E. eximia	x			*E. Wilkinsoniana*		·	·
E. punctata	x		x	*E. acervula*		·	·
A. lanceolata	x		x	*E. sparsifolia*		x	·
A. Bakeri	x		x	*E. saligna*		x	
E. umbra	x			*E. acmenioides*		x	
E. botryoides	x			*E. hemiphloia*		x	
E. capitellata	x			*E. tereticornis*		x	
E. eugenioides	x	x	x	*E. amplifolia*		x	
E. resinifera	x	·	x	*E. longifolia*		x	
E. Blaxlandi	x			*E. crebra*		x	
E. maculosa	x			*E. Beyeri*		x	
E. rubida	x			*E. sideroxylon*		x	
E. oreades	x			*E. Macarthuri*		x′	
E. dives	x			*E. ovata*		x′	
E. notabilis	x			*E. stellulata*		x′	
E. Consideniana	x			*E. pauciflora*		x′	
E. urceolaris	x′			*E. maculata*			·
E. fraxinoides	x′			*E. Baueriana*		x	
E. pilularis	x		x	*E. Rudderi*		x	
E. radiata	x	x′		*E. Parramattensis*		·	
E. goniocalyx	x	x′					

types in Table 5 and on page 122, for instance, would be a separate association, and one could doubtless discover a dozen more of them.

To avoid the manifest disadvantages of this procedure, the writer has described all forests on sandstone as Mixed *Eucalyptus* Forest. There are indeed striking contrasts among these forests, but as reference to Table 3 shows, there is so much overlap that *no species are peculiar to any one variant* of the Mixed *Eucalyptus* Forest. On the shale, however, there is a sufficiently clear distinction between the common species in the Cumberland Basin, on the Hornsby Plateau and on the Wingecarribee Tableland (Table 8) to justify the classification into two well represented associations: the *E. hemiphloia–E. tereticornis* Association, and the *E. saligna–E. pilularis* Association, with fragments of two other associations: the *E. viminalis–E. fastigata* Association and the *E. pauciflora–E. stellulata* Association.

There is a striking difference both in regard to floristics and physiognomy between the sandstone and shale forests, irrespective of the climate. Table 12 provides evidence for this specific effect of soil on species distribution. In sandstone gullies on the Hornsby Plateau where the water balance in the soil is comparable to that on the outliers of shale, one does not find typical *E. saligna–E. pilularis* shale forest; only *E. pilularis* is common to both habitats. It is apparent, therefore, that the restriction of certain species to certain soils is determined by some factor other than soil moisture. The distribution of species over the sandstone and shale regions is determined primarily by rainfall and altitude, the former through its effect on the P/E, and the latter through its effect on the temperature range and the length of the frost-free period. The edaphic and climatic tolerance of the more important species is summarized by Text-figure 5.

Further analysis of the forest vegetation in the central coastal area of New South Wales must await studies in the comparative physiology of species of *Eucalyptus*. The factors which restrict *E. haemastoma* to poor sandstone soils, *E. hemiphloia* to dry shale soils, *E. dives* to high altitudes, and *E. botryoides* to situations near the sea, will doubtless be difficult to analyse; but until the physiological data are available, any views as to the cause of the distribution of forest types must remain mere speculation.

SUMMARY.

A brief account is given of the distribution of forest types on the soils derived from Hawkesbury Sandstone and Wianamatta Shale in the central coastal area of New South Wales.

For reasons discussed in the body of the paper, forests on sandstone are classified as variants of one association: the Mixed *Eucalyptus* Forest; and forests on shale fall into several distinct associations: *E. hemiphloia–E. tereticornis*, *E. saligna–E. pilularis*, *E. viminalis–E. fastigata*, and *E. pauciflora–E. stellulata* Associations.

Data are given which illustrate the remarkable specificity of species of *Eucalyptus* to ecological conditions, in particular to rainfall, altitude, and soil type. The bearing of this phenomenon upon the problem of classifying the forests is discussed.

Acknowledgement.

The author has pleasure in thanking Professor Eric Ashby, Botany School, University of Sydney, for his stimulating criticism and help in the preparation of this paper.

Literature Cited.

BLAKELY, W. F., 1934.—A Key to the Eucalypts. The Worker Trustees Press. Sydney.

CLEMENTS, F. E., 1936.—Nature and Structure of the Climax, *J. Ecology*, xxiv, 252-283.

FRASER, LILIAN, and VICKERY, JOYCE W., 1939.—The Ecology of the Upper Williams River and Barrington Tops Districts. iii. The Eucalypt Forests and General Discussion. PROC. LINN. SOC. N.S.W., lxiv, 1-33.

LINDQUIST, B., 1931.—Den Skandinaviska Bokskogens Biologi. Stockholm.

OSVALD, H., 1923.—Die Vegetation des Hochmoores Komosse. Uppsala.

PIDGEON, ILMA M., 1937.—The Ecology of the Central Coastal Area of New South Wales. i. The Environment and General Features of the Vegetation. PROC. LINN. SOC. N.S.W., lxii, 315-340.

————, 1938.—Id., ii. Plant Succession on the Hawkesbury Sandstone. Ibid., lxiii, 1-26.

————, 1940.—Id., iii. Types of Primary Succession. Ibid., lxv, 221-249.

PRESCOTT, J. A., 1934.—Single Value Climatic Factors. *Trans. Roy. Soc. S. Aust.*, lviii, 48-61.

PRYOR, L., 1939.—The Vegetation of the Australian Capital Territory. A Study of the Synecology. (M.Sc. Thesis, University of Adelaide.)